Planning Remediation with Multi-Criteria Decision Analysis

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"How To" Questions

- **How to quantify risks and benefits associated with alternative management strategies?**
- **How to consider Model, Parameter, and Scenario Uncertainty with respect to:**
  - **Variability of management options?**
  - **Stakeholder value judgments?**
- **How to plan for situations with limited knowledge, high uncertainty and variability?**
- **<u>Answer</u>:**
  - **Couple traditional risk assessment and planning with multi-criteria decision analysis (MCDA) to support regulatory decision making.**

Presentation Overview

- **Risk-based Planning**
  - **"Top-down" and "Bottom-up"**
- **Risk and Uncertainty**
  - **Traditional way**
  - **Need for formal decision analysis**
- **RA/MCDA**
  - **Select performance metrics**
  - **Examples**
    - **Oil spill response planning**
    - **Sediment Management**
- **Key Take-Away Points**

Risk-based Planning: "Top-down" Drivers

Match responses to mission. Track performance.

- The Government Performance and Results Act (GPRA)
  - Establishment of "strategic planning and performance measurement in the Federal Government" (OMB, 1993).
  - Better planning, greater accountability, and straightforward performance evaluation of government.
- OMB Program Assessment Rating Tool (PART)
  - Performance metrics gauged with "yes/no" questions.
  - Scores:
    - Program purpose & design
    - Strategic planning
    - Management
    - Results & accountability

Risk-based Planning: "Bottom-up" Drivers

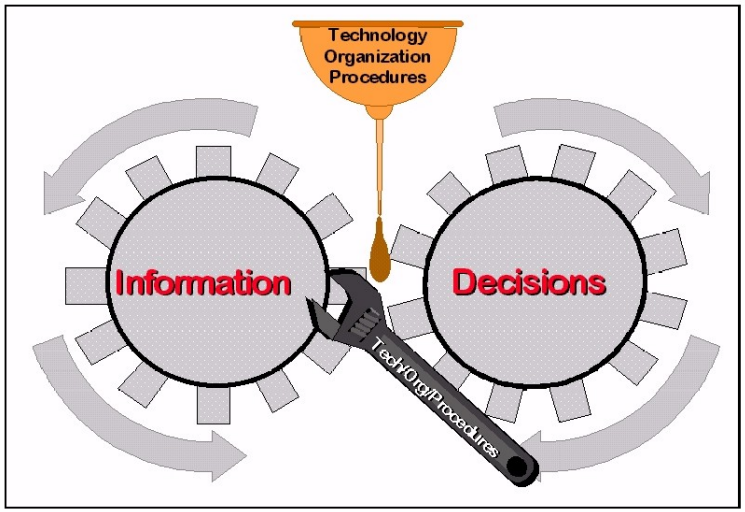
Responses must reflect local community values.
Stakeholders should understand the responses.

- **Fear:**
  - **Victimization**
  - **Uncompensated loss**
- **Risk:**
  - **Layperson: Risk = Hazard x Perception**
  - **Expert: Risk = Hazard x Exposure x Consequence**

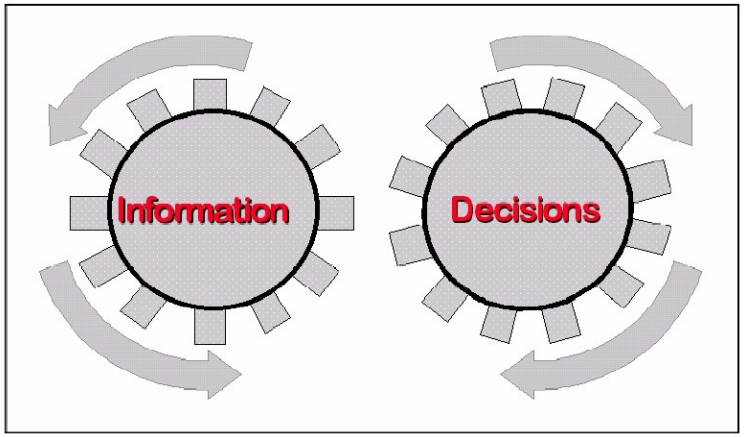
- **Planning challenges:**
  - **Trust**
  - **Control**
  - **Process**
  - **Information**
  - **Timing**

nformation and Planning/Decision Cycle

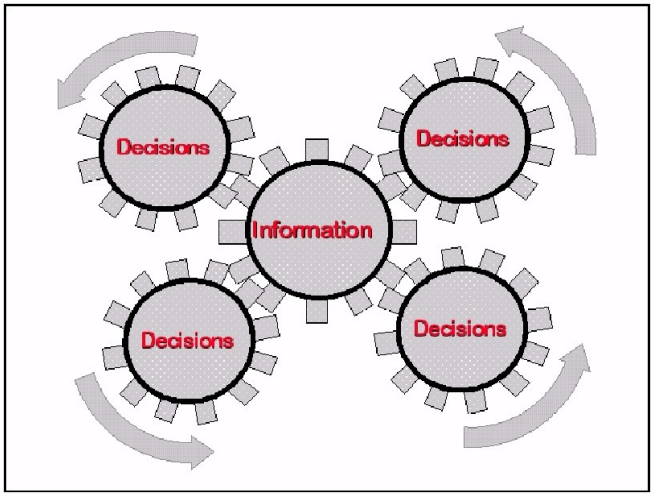
Information gathering and decision-making are two separate cycles in environmental ement



After Roman, 1996

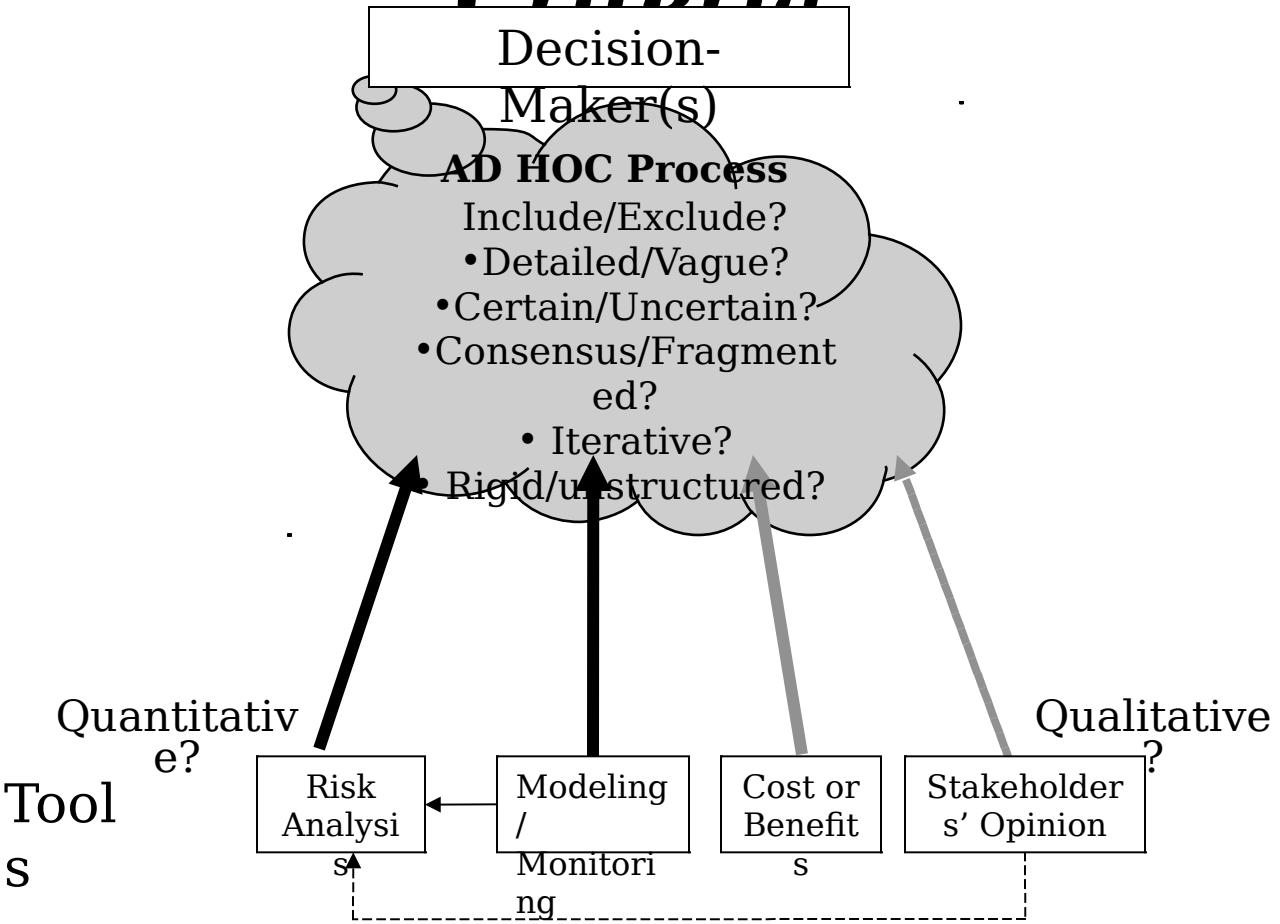


Modeling/Software/GIS… Technology-based Fix in Information Age



Integration – Need for Revolutionary Changes

Challenge: Multiple & Uncertain Criteria



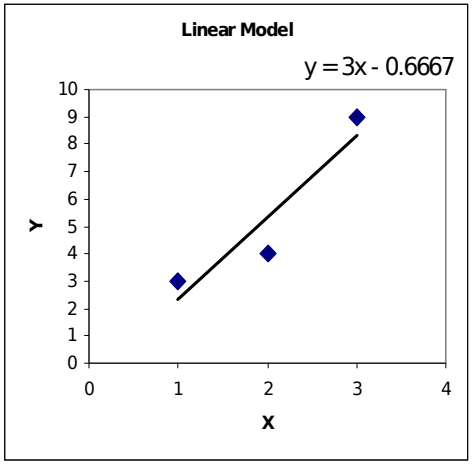
Human Complications

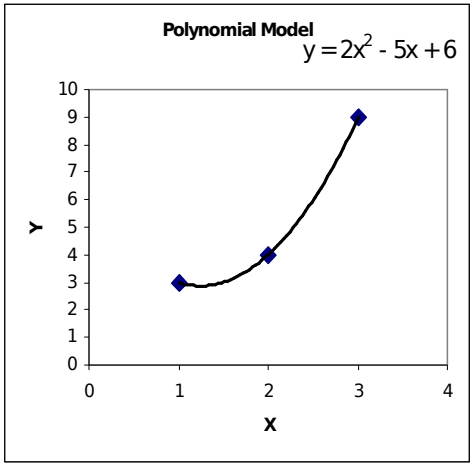
- “Humans are quite bad at making complex, unaided decisions” (Slovic et al., 1977).
- Individuals respond to complex challenges by using intuition and/or personal experience to find the easiest solution.
- At best, groups can do about as well as a well-informed individuals if the group has some natural systems thinkers within it.
- Groups can devolve into entrenched positions resistant to compromise
- “There is a temptation to think that honesty and common sense will suffice” (IWR-Drought Study p.vi)

Model Uncertainty

Mechanism meets *Expert Judgment*

- Differences in model structure result from:
  - Model objectives
  - Computational capabilities
  - Data availability
  - Knowledge and technical expertise of the group
- Can be addressed by:
  - Considering alternative model structures
  - Weighting and combining models
  - Eliciting expert judgment

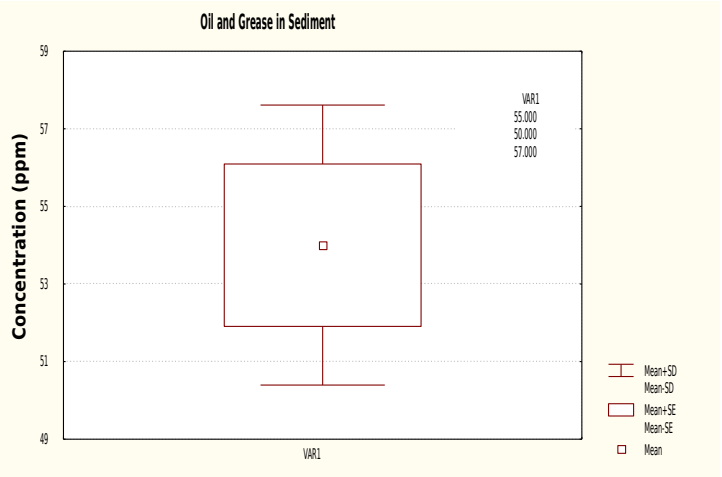




Parameter Uncertainty

Risk assessment deals with large and often unquantifiable parameter ranges

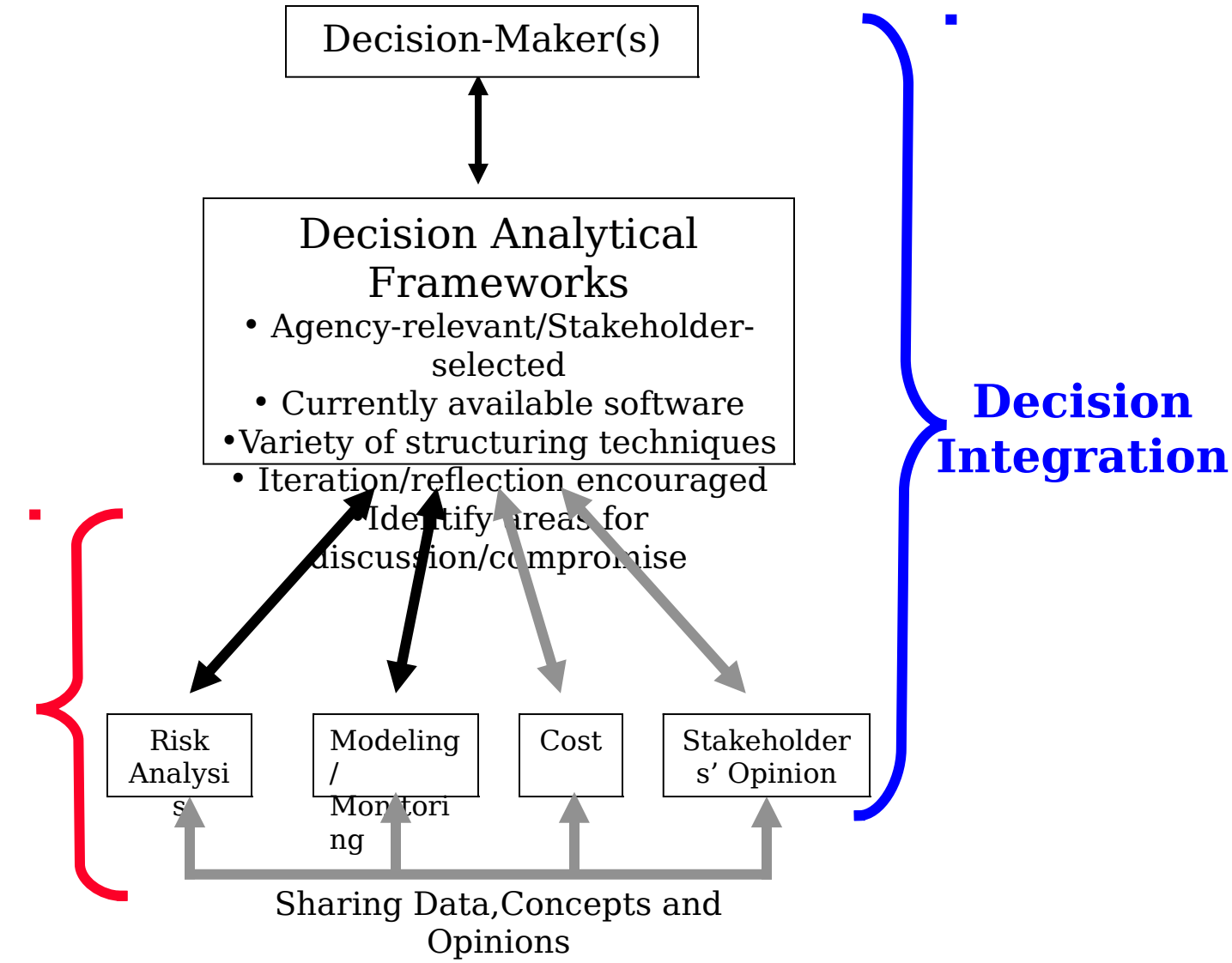
- *Uncertainty* and *variability* inherent:
  - Data availability
  - Expert judgment
  - Empirical distributions
- Manage with:
  - Probability
    - Monte Carlo simulati
  - Analytical techniques
    - Uncertainty propagation
  - Expert estimates



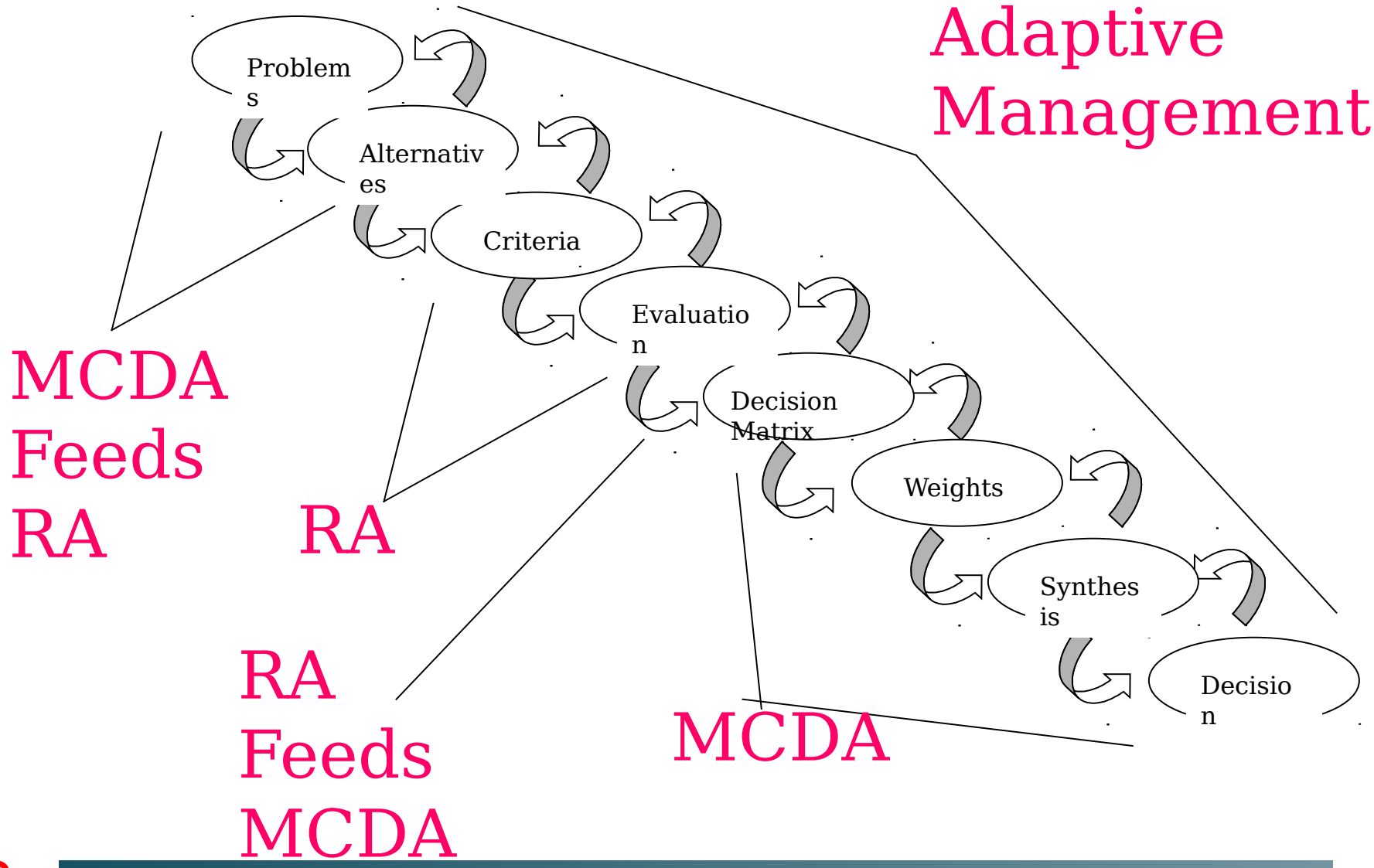
Multi-Criteria Decision Analysis and Tools

- People can't effectively analyze multiple streams of dissimilar information
- MCDA to integrate various inputs with stakeholder/technical expert values
- MCDA to communicate model/monitoring outputs for regulation, planning and stakeholder understanding
- Risk-based MCDA to organize and integrate rankings to better inform decisions

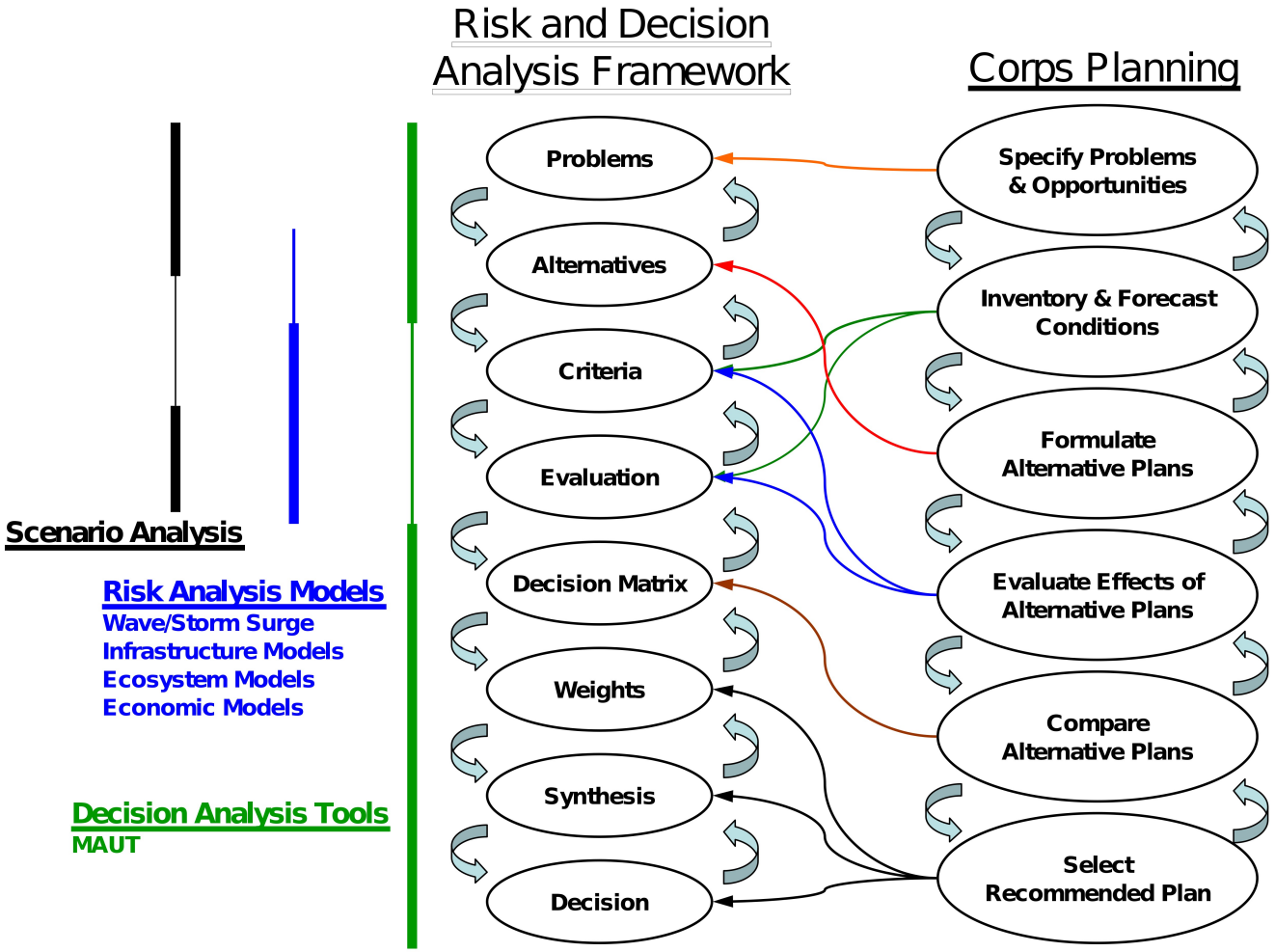
Decision Tool Integration



Linking RA, AM and MCDA



Restoration Planning for Coastal LA and MS



*Example 1: Oil Spill**

- Multiple stakeholders
  - Agencies (federal, state, loc
  - Responsible parties
  - Local residents
  - NGOs (business, environmental, etc.)
- Integrate deliberation and science
  - Link goals, objectives, metrics, measures
- Compatible with
  - Existing planning, decision-making, and assessment processes
- Completed as part of preparedness planning

* Oil Spill Response Planning per Linkov, Seager, Figueira, Tkachuk, Levchenko, Trevonnen (2007), funding by NOAA through CRRC, UNH.

Planning Oil Spill Response

Resources
- Oil containment booms deployed
- Volunteers deployed
- Sandbags deployed

Challenges
- Minimize permitting delays
- Rehab many oiled birds
- Minimize time booming and double-booming sensitive areas

Tradeoffs
- Redirect or contain oil
- Numbers of fish vs. birds or other wildlife killed or injured
- “Appropriate” (not exotic) animals rehabilitated and released
- Change to beach and sandbar from responses
- Types of animals and vegetation remaining after response

Good Measures

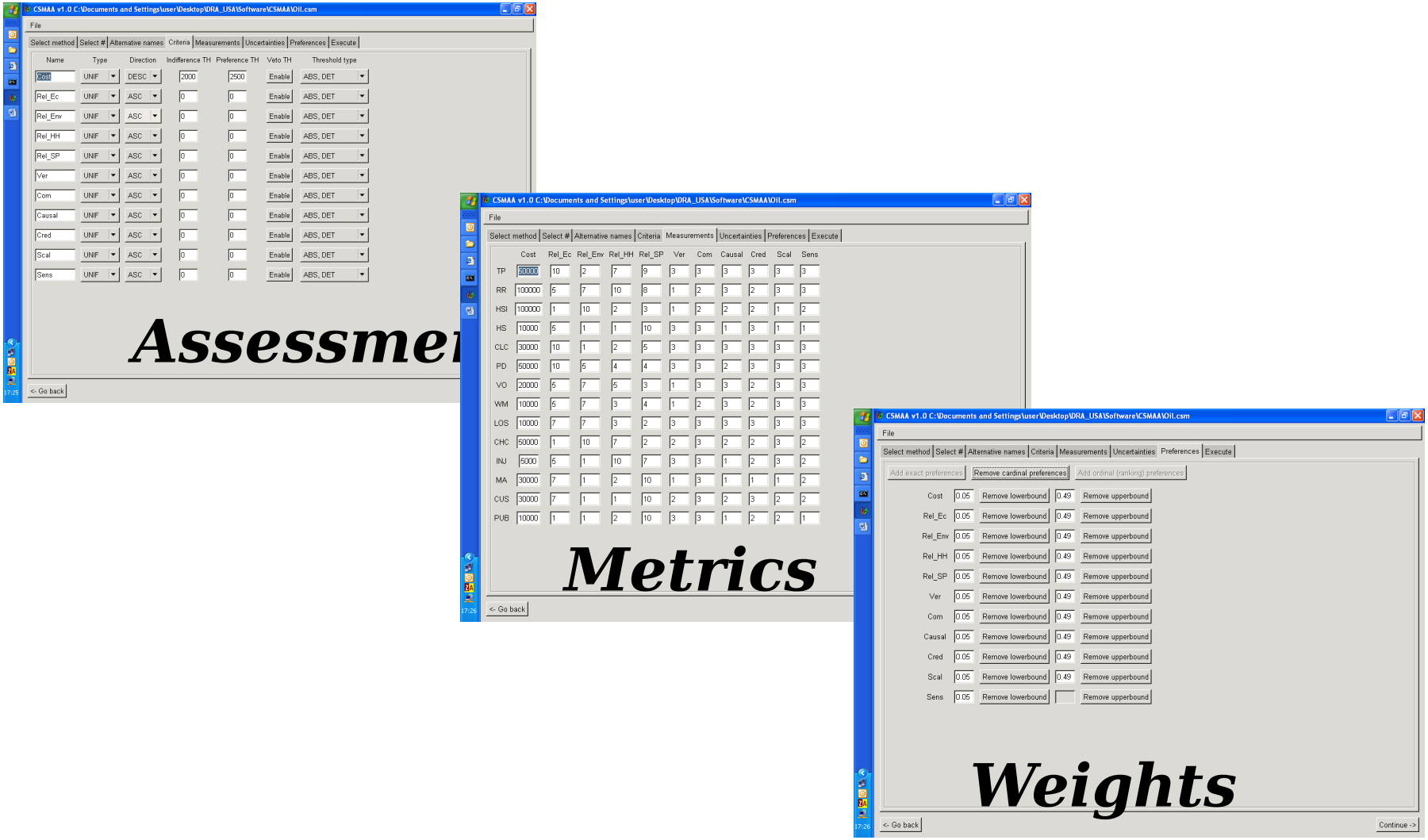
- Scientifically verifiable
- Cost-effective
- Easy to communicate to a wide audience
- Relevant to what people care about
- Decision or action relevant
- Credible
- Scalable over appropriate time and geographic region
- Sensitive to change

Oil Spill Response Metrics Taxonomy

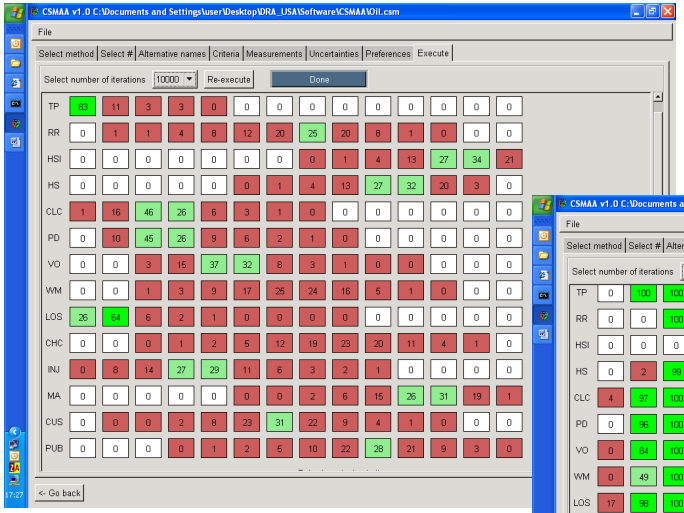
Type of Information Measured

Economic	Thermodynamic	Environmental	Ecological	Human Health	Socio-Political
Clean up costs.	**Volume of oil spilled, recovered, des-troyed, or contained.**	**Chemical conc & toxicity.**	Wildlife deaths or populations, fecundity and recovery rates.	**Threatened pop'n**	**Newspaper column inches, minutes TV coverage, web hits.**
Property & eco-system damage.		Habitat suitability, e.g., acres shellfish bed.		Quality-adjusted-life-years (QALYS)	
Ecosystem damages or lost services.	Slick area and thickness.	**Length of oiled shoreline.**	Biodiversity.	Disability-adjusted-life-years (DALYS)	Volunteerism.
Lost marginal profits.	**Mass of clean up wastes generated.**	Degradation rates.	Catch sizes.	Life-expectancy	**Public meeting attendance.**
Volunteer opportunity costs.	Volume cleaning agent deployed.	**Residual Risk**	Plantings, seedings.	**Injuries**	**Critical sites pro-tected**
			Habitat Suitability		**Historic sites pro-tected**

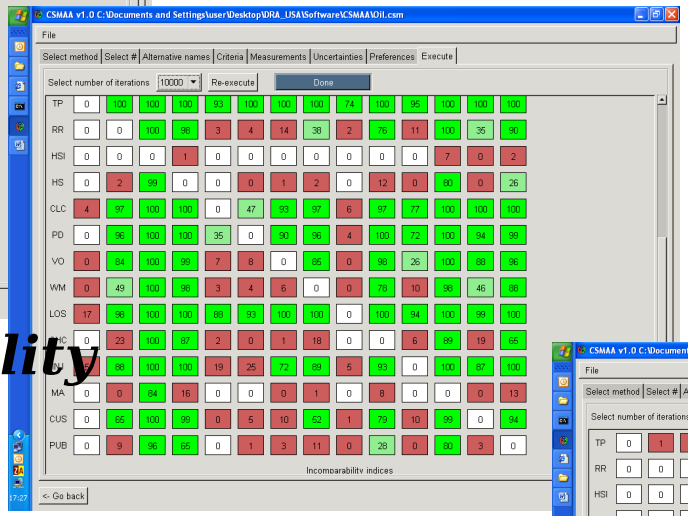
Criteria



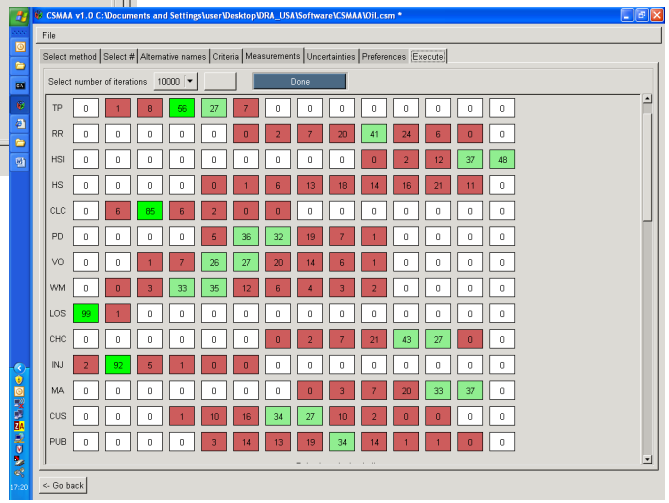
Analysis



Rank Acceptability



Pairwise
Metrics
Domination



Sensitivity Analysis

Example 2: NY/NJ Harbor

Example: NY/NJ Harbor

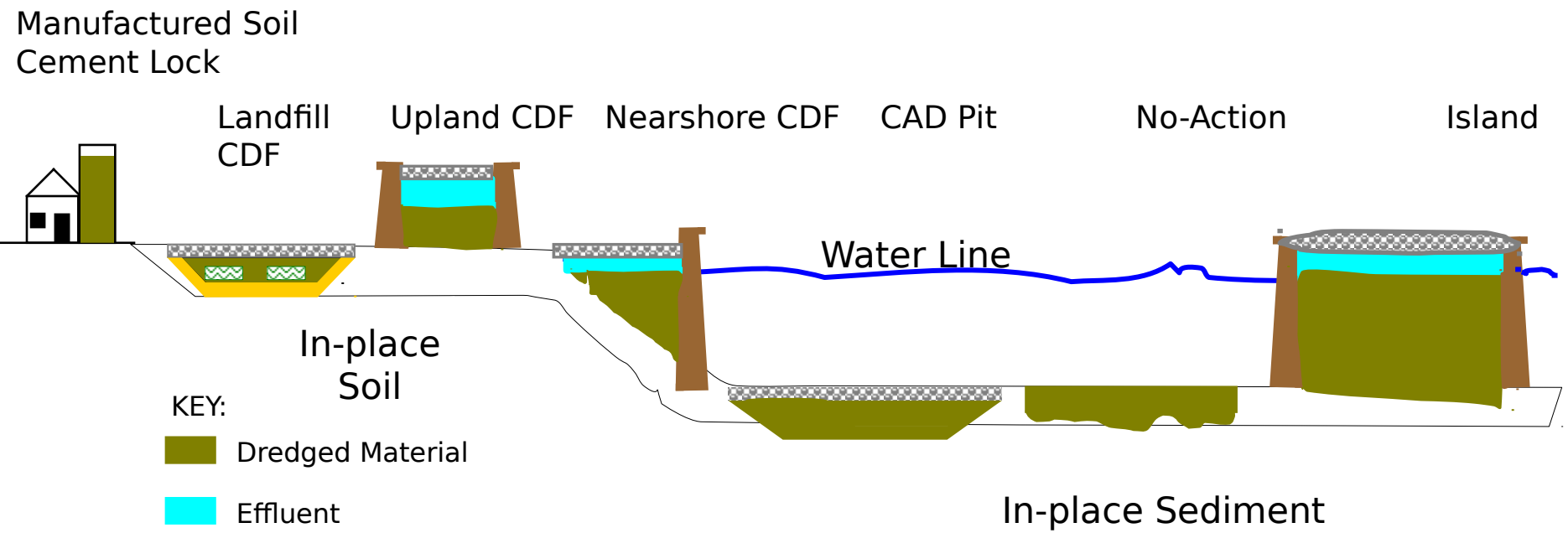
Issues

- **Harbor among most polluted in U.S.**
- **>10^6 yd^3 fail regional criteria for ocean disposal**
- **Existing disposal site closed 1 Sep. 97**
- **Proposed deepening**

Example: Decision Methodology

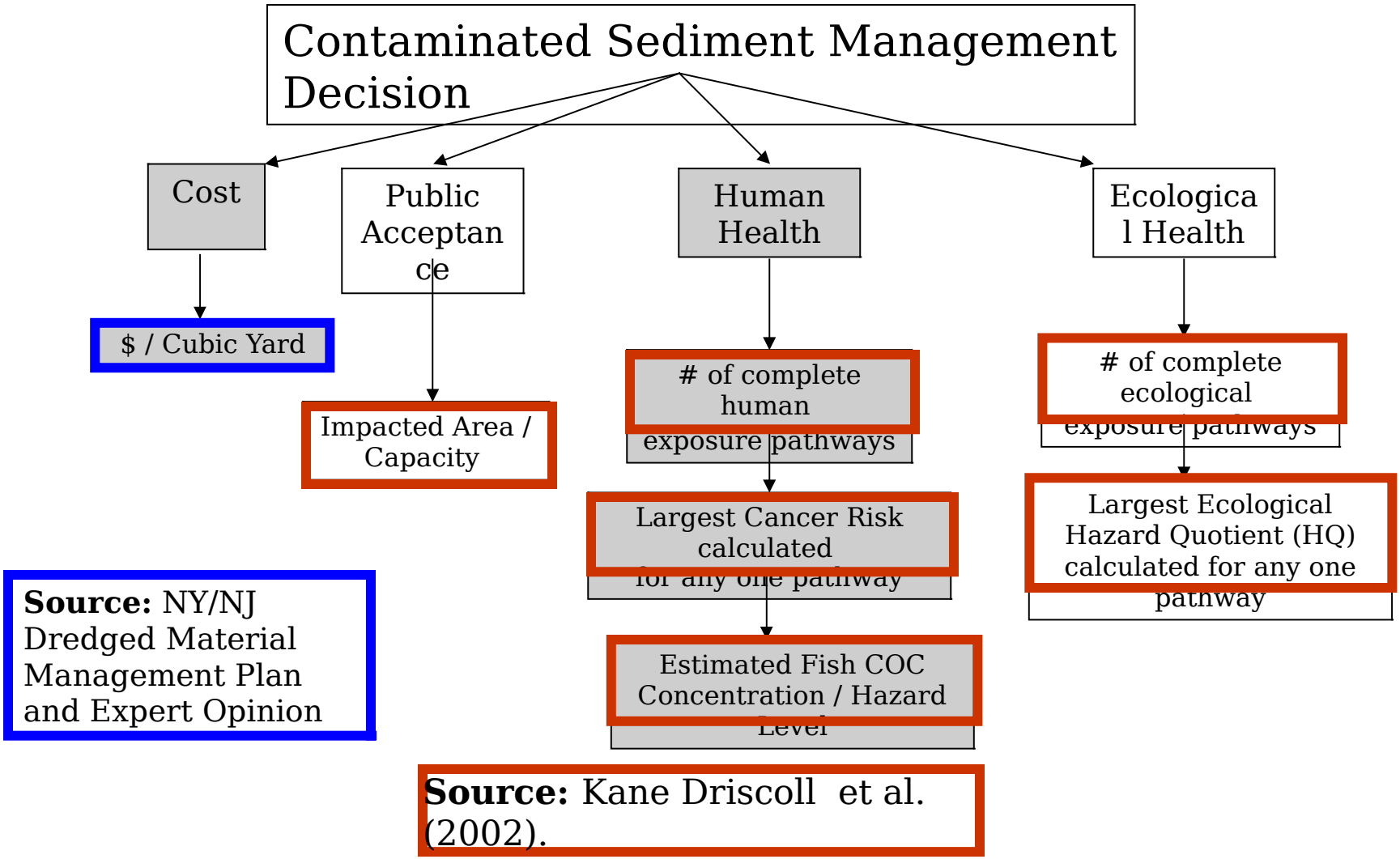
- **Proof of Concept Study**
- **Objectives**
  - **Integrate risk assessment, cost, stakeholder values**
  - **Criteria/performance measures from published data and proposed costs**
  - **Test decision tools, methodology and results**
- **How?**
  - **Set options for management of contaminated sediment**
  - **Set decision criteria/performance measures**
  - **Software - Criterium DecisionPlus**
  - **Stakeholder Values / Expert Surveys**
    - **USACE/EPA meetings (New Orleans 2004)**
    - **SRA/USACE meeting (Palm Beach 2004)**

Conceptual Illustration of Disposal Alternatives

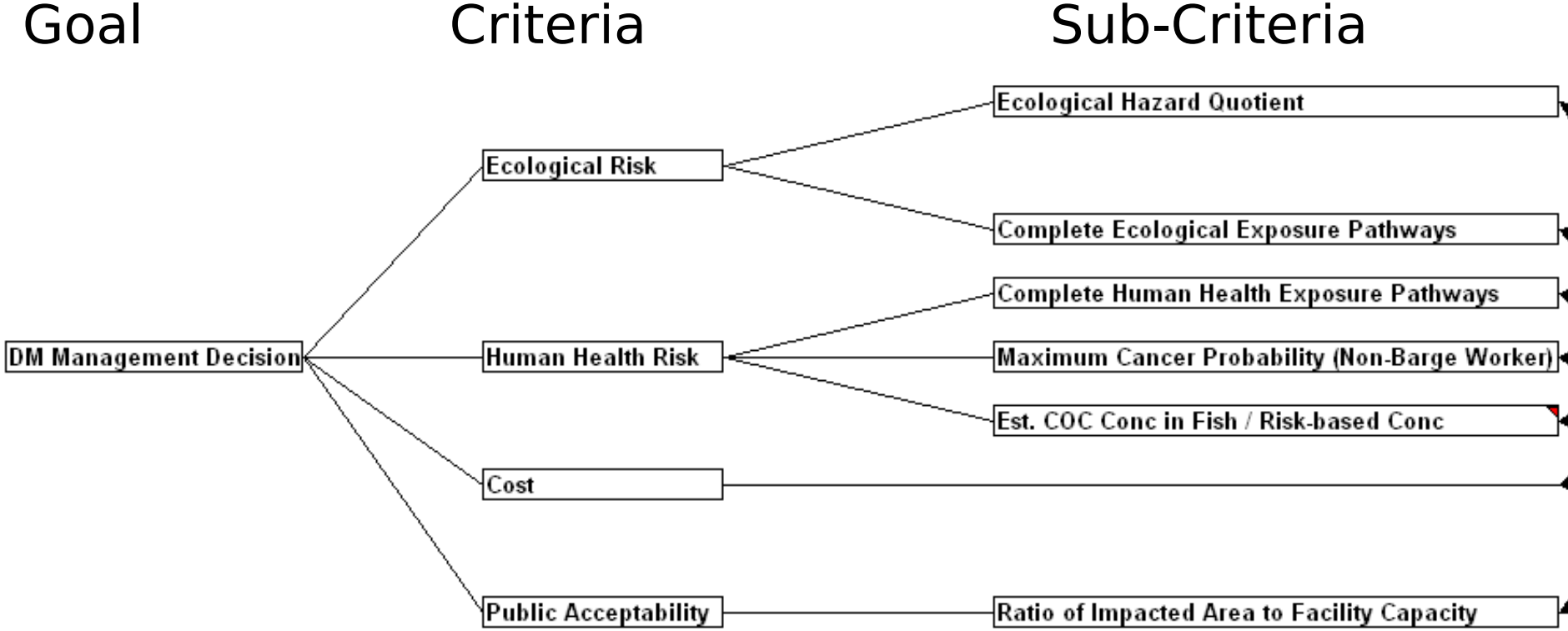


Kane Driscoll, S.B., W.T. Wickwire, J.J. Cura, D.J. Vorhees, C.L. Butler, D.W. Moore, T.S. Bridges. 2002. A comparative screening-level ecological and human health risk assessment for dredged material management alternatives in New York/New Jersey Harbor. *International Journal of Human and Ecological Risk Assessment* 8: 603-626.

Decision Criteria: NY/NJ Harbor

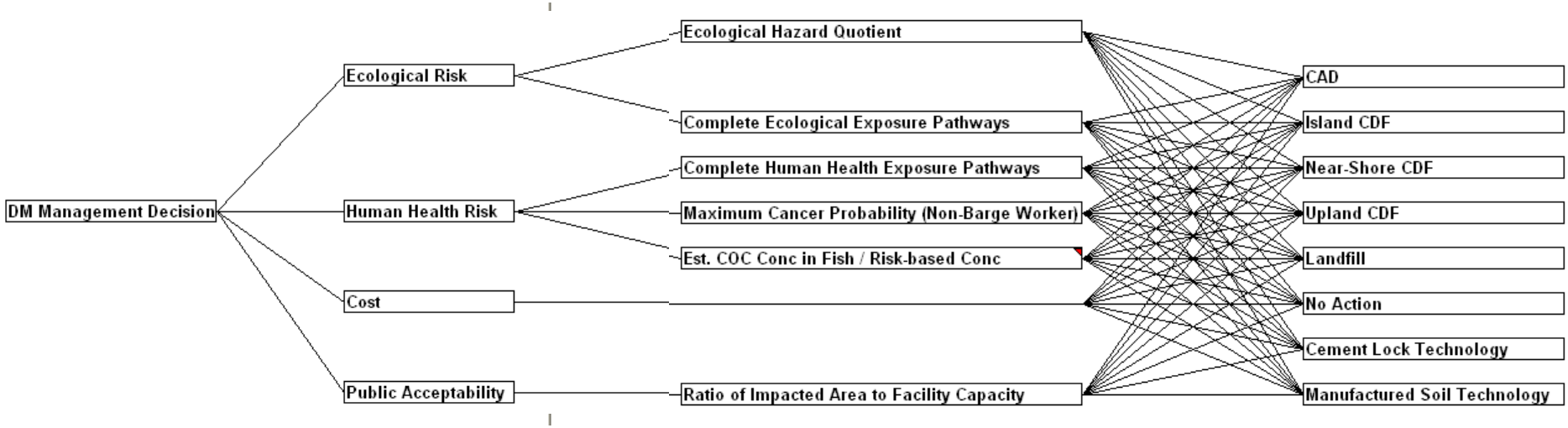

Contaminated Sediment Management Decision
Cost
Public Acceptance
Human Health
Ecological Health
$ / Cubic Yard
Impacted Area / Capacity
# of complete human exposure pathways
Largest Cancer Risk calculated for any one pathway
Estimated Fish COC Concentration / Hazard Level
# of complete ecological exposure pathways
Largest Ecological Hazard Quotient (HQ) calculated for any one pathway
Source: NY/NJ Dredged Material Management Plan and Expert Opinion
Source: Kane Driscoll et al. (2002).

NY/NJ Harbor in Criterium DecisionPlus



NY/NJ Harbor in Criterium DecisionPlus

Goal Criteria Sub-Criteria Alternatives



Hierarchy Rating Technique: **Weights**

Alternatives Rating Technique:
SMART
with linear value functions

Criteria Levels for Each DM Alternative

	Cost	Public Acceptab	Ecological Risk		Human Health Risk		
DM Alternatives	($/CY)	Impacted Area/Capacity (acres / MCY)	Ecological Exposure Pathways	Magnitude of Ecological HQ	Human Exposure Pathways	Magnitude of Maximum Cancer Risk	Estimated Fish COC / Risk Level
CAD	5-29	4400	23	680	18	2.8 E -5	28
Island CDF	25-35	980	38	2100	24	9.2 E -5	92
Near-shore CDF	15-25	**6500**	38	900	24	3.8 E -5	38
Upland CDF	20-25	**6500**	38	900	24	3.8 E -5	38
Landfill	29-70	0	0	0	21	3.2 E –4	0
No Action	**0-5**	0	**41**	**5200**	12	2.2 E –4	**220**
Cement-Lock	**54-75**	0	14	0.00002	**25**	2.0 E -5	0
Manufactured Soil	54-60	750	18	8.7	22	**1.0 E –3**	0

Blue Text: Most Acceptable Value

Red Text: Least Acceptable Value

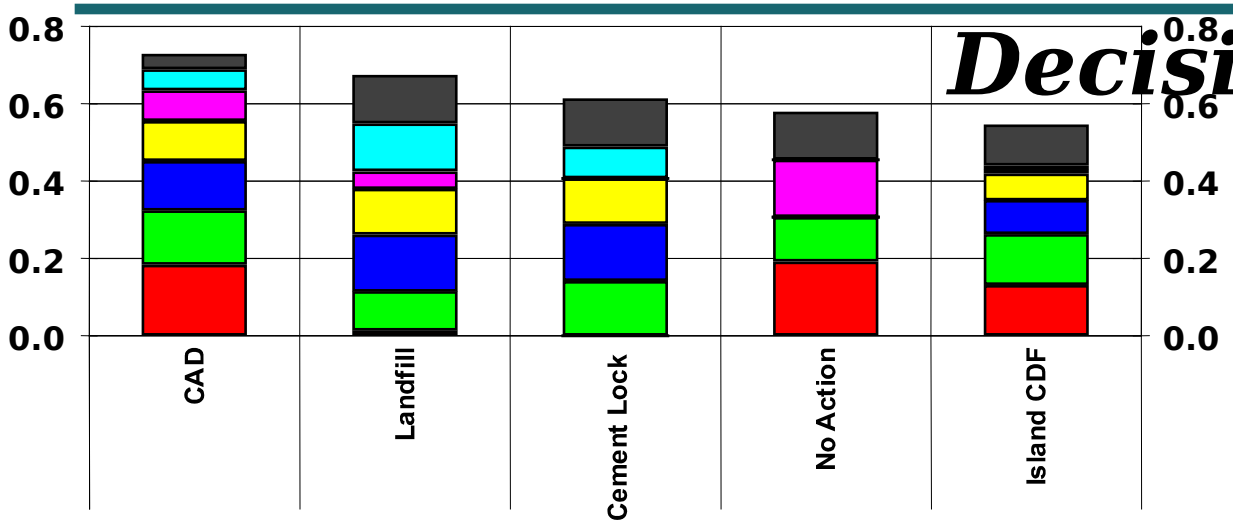
USACE/EPA DM Managers Meeting: NY/NJ Harbor Weighting Form

Attribute Swung from Worst to best	Consequence to compare	Rank (1-9)	Rate (0-100)
Benchmark: Worst case on everything	Impacted Area/Capacity of Facility = 6500 (acres/ 10^6 cubic yards) Magnitude of Ecological Hazard Quotient – Maximum Exposure = 5200 Number of Complete Ecological Exposure Pathways = 41 Number of Complete Human Exposure Pathways = 25 Magnitude of Maximum Cancer Probability (Non-barge worker) = $1* 10^{-3}$ Ratio of Estimated Concentration of COCs in Fish to Risk-Based Concentrations = 220 Cost = 54-75 $/CY	9	0
Impacted Area/Capacity of Facility	Change from 6500 (acres/ 10^6 cubic yards) to 0 (acres/ 10^6 cubic yards)		
Magnitude of Ecological Hazard Quotient –Maximum Exposure	Change from 5200 to 0		
Number of Complete Ecological Exposure Pathways	Change from 41 to 0		
Number of Complete Human Exposure Pathways	Change from 25 to 12		
Magnitude of Maximum Cancer Probability (Non-barge worker)	Change from $1* 10^{-3}$ to $0.028 * 10^{-3}$		
Ratio of Estimated Concentration of COCs in Fish to Risk-Based Concentrations	Change from 220 to 0		
Cost	Change from (54-75 $/CY) to (0-5 $/CY)		

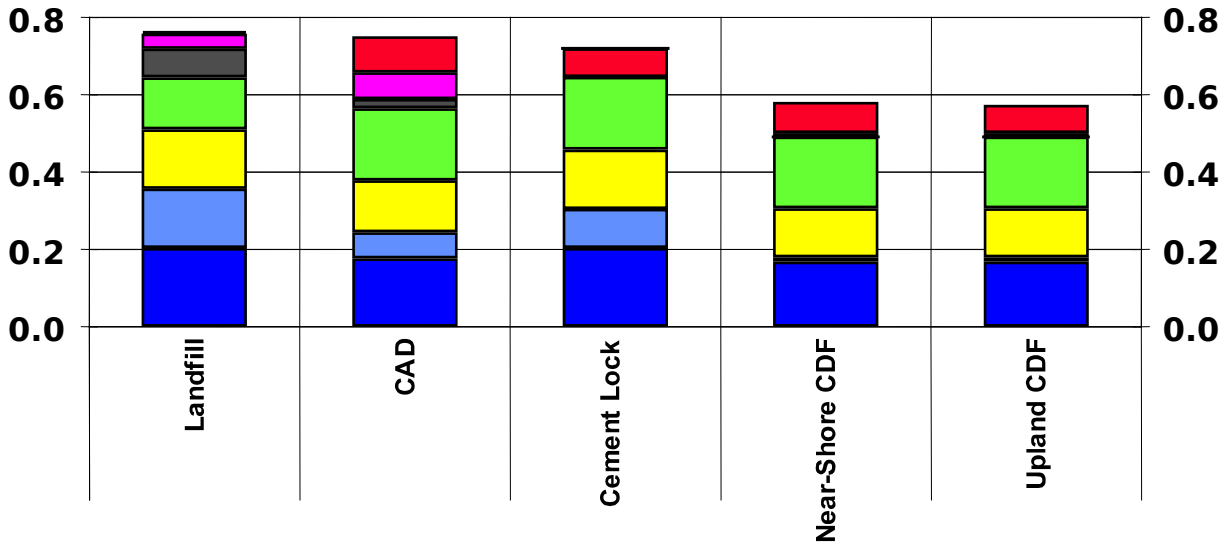
USACE/EPA Survey Results: Criteria Weights (%)

	EPA	USACE	SRA
Public Acceptability	**7.4**	**12.5**	10.77
Ecological Health	**35.6**	**27.1**	32.45
Human Health	**47.0**	**40.7**	44.10
Cost	**10.0**	**19.7**	12.67

Criteria Contributions to Decision Score



USACE weighting



EPA weighting

Cost
Maximum Cancer Probability (Non-Barge
Ecological Hazard Quotient
Est. COC Conc in Fish / Risk-based Conc
Complete Human Health Exposure Pathwa
Complete Ecological Exposure Pathways
Ratio of Impacted Area to Facility Capacit

Solution vs. MCDA Method: Does it Matter?

Software & Method	**Alternatives (NY Case Study)**							
	CAD	***Island CDF***	***Near-Sh CDF***	***Upland CDF***	***Landfl***	***Cement Lock***	***Manuf Soil***	***NoAct***
ExpertChoice, AHP	5	8	6	7	2	**1**	3	4
DecisionLab, PROMETHEE	3	8	5	6	2	**1**	4	7
CritDecPlus, SMART	2	7	4	5	**1**	3	6	8

Risk Assessment, Adaptive Management and MCDA Implementation Framework

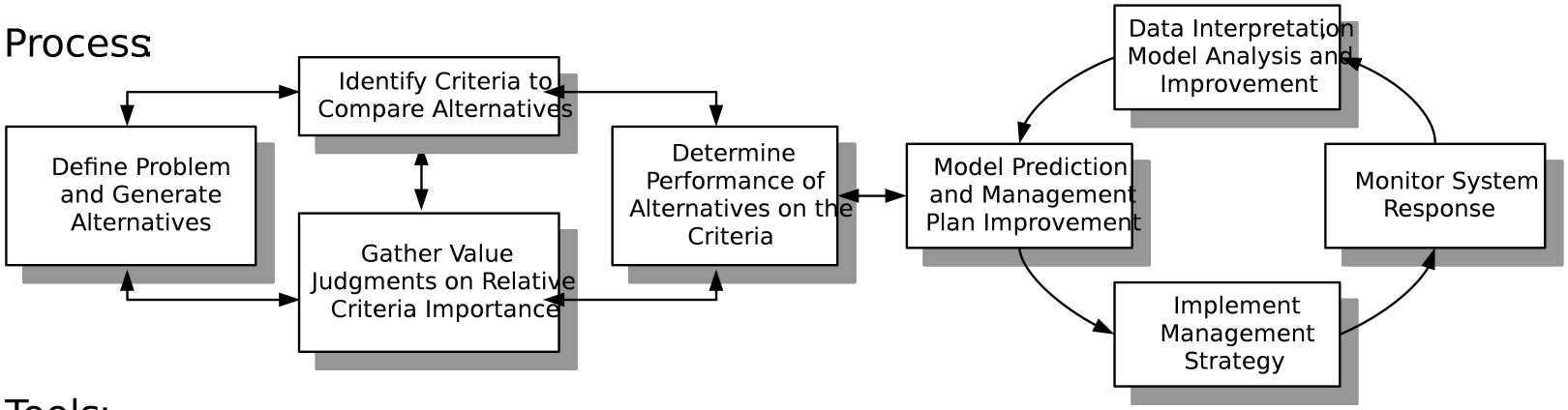
People:

Policy Decision Maker(s)

Scientists and Engineers

Stakeholders (Public, Business, Interest Groups)

Process:


Identify Criteria to Compare Alternatives
Define Problem and Generate Alternatives
Determine Performance of Alternatives on the Criteria
Gather Value Judgments on Relative Criteria Importance
Data Interpretation Model Analysis and Improvement
Model Prediction and Management Plan Improvement
Monitor System Response
Implement Management Strategy

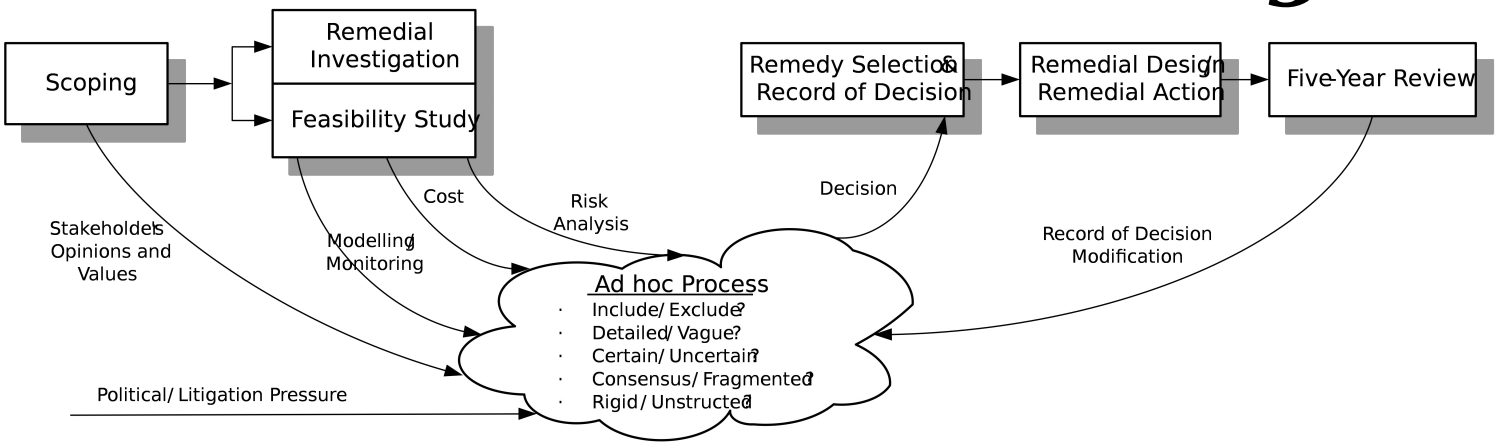
Tools:

Environmental Assessment/Modeling (Risk/Ecological/Environmental Assessment and Simulation Models)

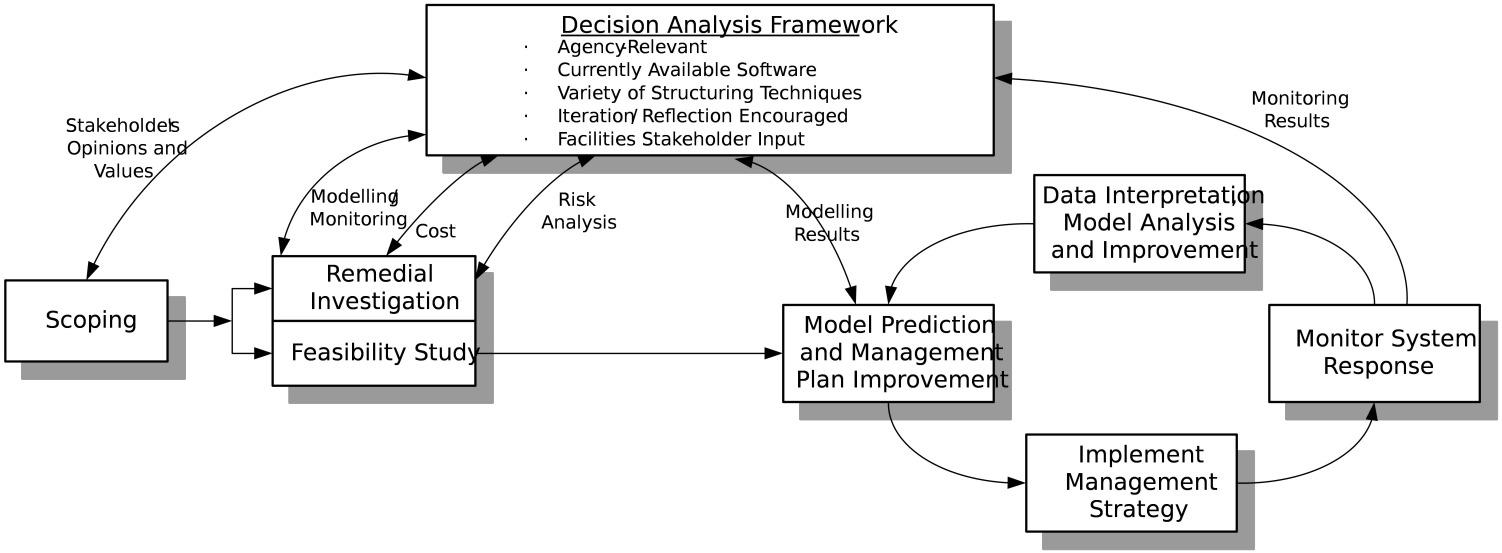
Decision Analysis (Group Decision Making Techniques/Decision Methodologies and Software)

Adaptive Risk-Based Planning

a) Ad hoc Decision Process



b) Adaptive Decision Analysis Framework



Key Take-Away Points

Risk-Based MCDA offers planners:

- **Reproducible and defensible management of complex multiple criteria**
- **A means to define and gauge what is important**
- **Balancing of expert opinion and stakeholder values**
- **Better responses, better reporting with opportunities to more clearly get it “out on the table”**